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Madge—the British Military Microwave Landing System

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of the needs of the increasing number of graduates entering the Army; of the need to provide better opportunities for those who wish to obtain degrees whilst in the service; of the need not to discourage those who have had their fill of formal education and wish to get on with their soldiering. At the same time the syllabus, in addition to its military content, provides a starting point for instruction in those relevant professional academic studies which are built upon progressively throughout an officer's career.

Report from Industry

A new feature series designed to highlight and explain current industrial research and development in the defence field.

Madge—the British Military Microwave Landing System

by H. L. DERWENT

The author is Marketing Manager of The Microwave Interferometry Group of the Defence Systems Division for the MEL Equipment Co. Ltd. (Microwave Interferometry is concerned with the principle of measuring the difference in phase of two receivers receiving the same signal.)

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In October 1971 NATO announced that the British Microwave Landing System MADGE (Microwave Aircraft Digital Guidance Equipment) had won a Competition intended to select a new portable tactical approach and landing aid for use by NATO Air Forces. MADGE won this competition against similar systems entered by Germany (SETAC), France (SYDAC) and the USAF (TALAR IV).

This year HMG announced that it is planned to equip about 1,000 aircraft of the Army, Royal Navy and Royal Air Force with the MADGE system and provide 90 ground stations

Originally MADGE was designed and developed as a private venture project and was tested in collaboration with the Blind Landing Experimental Unit, RAE, Bedford, until entered by HMG for the NATO Competition. The research work was carried out by teams at Mullard Research Laboratories, Salfords, Redhill and the MEL Equipment Company's factory at Crawley, Sussex.

Since the announcement of this British Microwave Landing System (MLS) success, the private venture and Government Research and Development Programmes on MADGE have continued. Production engineering is progressing well. Early models will be available in 1974 and main production deliveries will commence early in 1975.

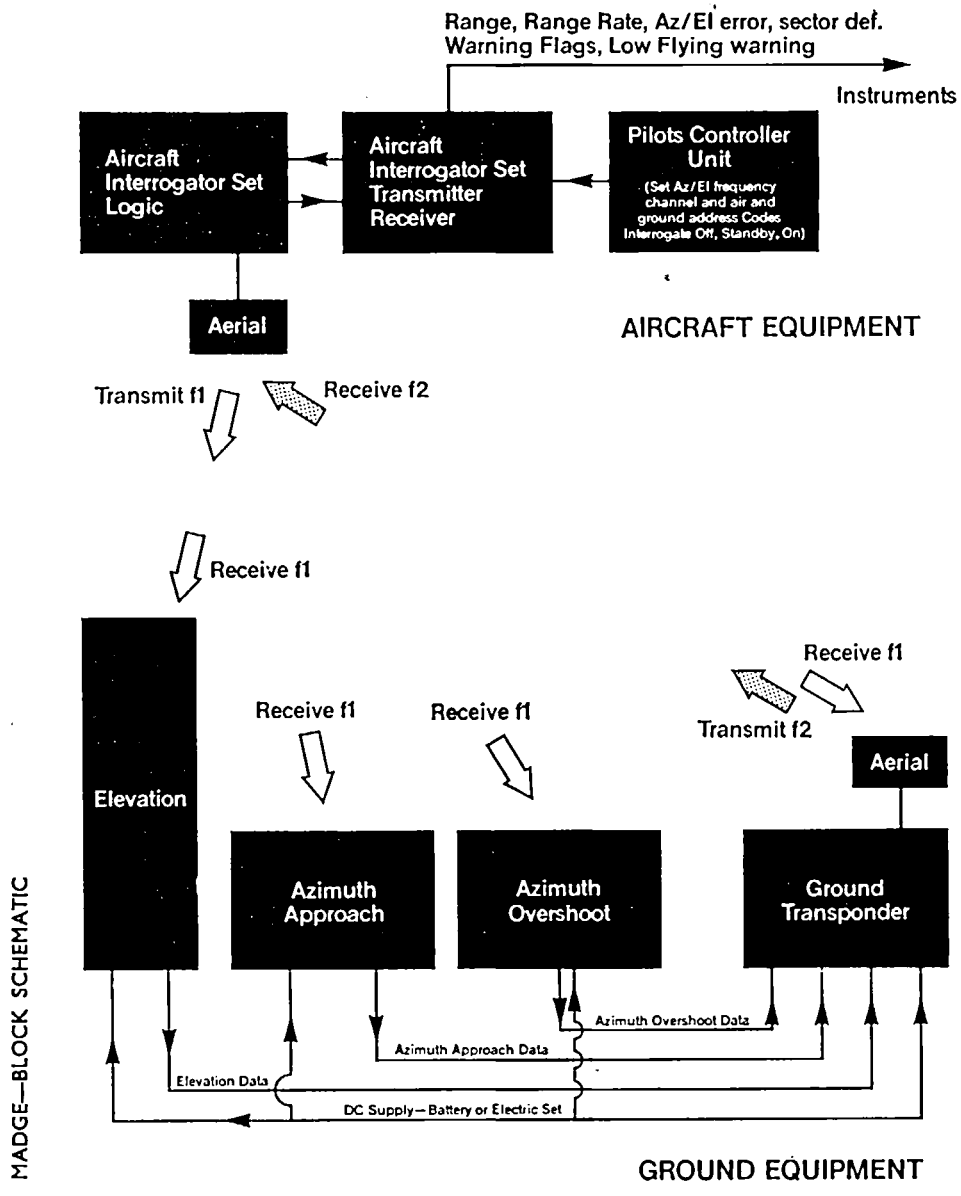
How MADGE works

The system comprises both aircraft and ground station elements operating in the 5 GHz band—the highest frequency with significant transmission through the atmosphere, particularly in heavy rain. Its operation is simple.

The pilot selects his approach path and the aircraft and ground station identity. When switched on the aircraft system interrogates the ground station which responds with elevation and azimuth angle information. The measured angle information is compared with the selected approach path data and error signals are derived to drive standard Instrument Landing System (ILS) instrumentation. The elapsed time of each interrogate transpond cycle is used to derive range and range rate information. The aircraft transceiver and the ground transponder use pulse coded modulation having a clock frequency of 1 MHz.

Flight Trials of over 450 hours, using Wessex, Varsity and AVRO 748 aircraft have been flown on MADGE to Test its *system accuracy*. By June 1971 these trials included the evaluation of the accuracy of the system over its *total* operational envelope. In addition the ground station was deployed on flat grass airfields, on runways, having sea, valley and mountain approaches. It has been operated near busy main roads and in the presence of a variety of reflective objects. These tests confirmed the overall capability of the system to operate satisfactorily in difficult propagation environments.

Since June 1971 the trials programme has been aimed at improving the *integrity of the system* performance at low elevation angles (below $1\frac{1}{2}°$). The primary object has been concerned with testing improved aerial, receiver and data processing tech-



niques designed to ensure complete ambiguity resolution down to the horizontal in the presence of very large horizontal surfaces of high reflectivity as well as large airfield obstructions. An associated objective has been trials to ensure that before breakdown occurs in the bottom of the elevation coverage the system will provide the pilot with a "fly up" signal. This is a "fail/safe" characteristic which is entirely separate from the low flying warning system.

A third objective has been to improve the sector definition characteristics of the ground station so that approach and overshoot sectors are clearly defined. This permits the instruments to read without change of sense when flying from approach to overshoot sectors and defines the edges of these sectors clearly. This reduces pilot work load.

Work to improve the performance and integrity of the *data link* has gone ahead. It has been established that the link makes negligible contribution to system beam noise. The data format has been revised to permit increased traffic handling capacity and to provide greater stretch potential for other applications of the data link for communication.

Operational characteristics

There are a number of technical features which are of particular interest. First the system makes use of multiple interferometers to obtain accurate angle measurement over a wide field both in azimuth ($\pm 45°$) and elevation (0–25°). The individual aerials in the array, together with their receivers and data processing, are so designed that adjustment in operational use is unnecessary.

The interrogation and reply signals carry a ground and air station address and this enables a large number of aircraft to work with several adjacent ground stations on the same frequency channel. Moreover the aircraft equipment can communicate with any ground station having the standard data terminal. Thus the system has unique potential for meeting a wide range of surveillance, navigation and communication requirements.

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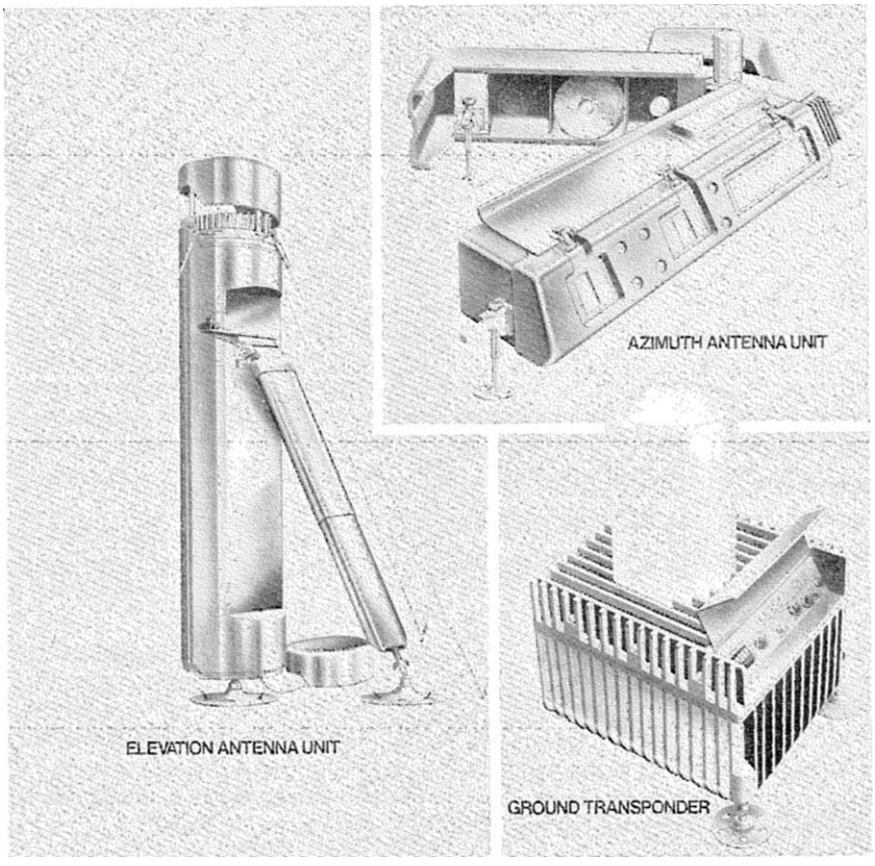

MADGE—GROUND STATION EQUIPMENT

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Angle, range and identity information is available in digital form and the system can be easily interfaced with auxiliary data processing equipment of ground based air defence and Air Traffic Control systems.

Resistance factors

The MADGE system has been designed to ensure very high integrity of the guidance data in the presence of interference. The duty cycle of the aircraft sub system is very low, the ratio of on to off time being in the ratio of 1 : 2,000. The ground station is passive except when interrogated by aircraft. The use of special data processing, discrete air and ground address codes, together with several levels of data validation ensure that false information is not accepted by the guidance system.

In addition, fault warning flags and lamps are provided in the aircraft and on the ground to give an immediate warning when any part of the system is working incorrectly.

Portability of the ground station

The ground station consists of four basic units. An elevation angle measuring array, and azimuth angle measuring array, a ground transponder and a 24V DC power supply. (A second azimuth unit can be used for overshoot or take off guidance.) These components fit easily into the standard Landrover and can be set up by two men in less than 15 minutes. It has also been designed to meet MOD Air Portability Criteria and is capable of being delivered to its operational site in a single parachute container.

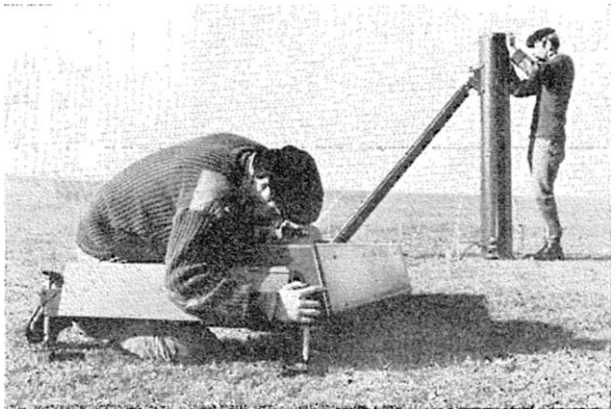
MADGE ground station unattended

This station can operate unattended, from a wide variety of 24 volt power supplies, commonly in service use. Built in test equipment is a main feature. In addition, tilt sensors are incorporated in the angle measuring arrays. Should any part of the ground station malfunction or the modules become seriously misaligned through blast or mechanical interference, the module is switched down and its failure indicated on the monitor panel of the ground transponder. This results in appropriate fault flag being raised in the aircraft.

Maintenance

Both the aircraft and ground elements of the system are provided with built in self test facilities. This equipment can be used to locate and diagnose faults. First and Second Line maintenance is minimised and is achieved through repair by replacement at sub assembly level.

The unique system arrangement together with the angle and range measuring techniques used in MADGE combine to give outstanding performance and operational *flexibility*. The operational resources of MADGE are set out here together with some indication of how these characteristics may be exploited as operational experience is gained.



MADGE on site

System operational resources

The MADGE I System concept provides the following facilities:

(a) An air to ground and ground to air digital communication system.
(b) A discrete aircraft and ground station address beacon system.
(c) A guidance system suitable for integration with aircraft control systems.
(d) A very accurate angle measuring system on the ground.
(e) An accurate range and range rate measuring system.
(f) A ground/air, air/ground ATC Air Defence interface.

The aircraft and ground elements cooperate through the air ground/ground air digital communication sub system, which carry out the following functions:

(a) *Aircraft sub system.* Provides:
  (i) Aircraft identification.
  (ii) Data as follows:
    (a) Elevation angle.
    (b) Azimuth angle.
    (c) Elevation displacement.
    (d) Azimuth displacement.
    (e) Range.
    (f) Range rate.
  (iii) Direct instrument and auto pilot interface.
  (iv) Approach path selection.
  (v) Ground station selection.
  (vi) Built in test monitor equipment.

(b) *Ground sub system.* Provides:
  (i) Ground station identification.
  (ii) Aircraft identification.
  (iii) Elevation angle.
  (iv) Azimuth angle.
  (v) Aircraft range.
  (vi) Aircraft range rate.
  (vii) Obstruction clearance warning.
  (viii) Built in test/monitoring equipment.

(c) *Air/ground, ground/air digital communication sub system*
  (i) 4 Air/ground channel frequencies.
  (ii) 3 Ground/air channel frequencies.
  (iii) Random access use of one frequency channel by more than 100 aircraft.
  (iv) A selection of up to 100 different aircraft identification codes and 12 ground station address codes.
  (v) Three separate data channels on a single frequency, guidance (50 Hz), guidance information (10 Hz) and an Administration channel (2–5 Hz).
  (vi) An information clock rate of 1 MHz on a single frequency channel.

Secondary operational roles

In *Area Navigation* the use of azimuth units and ground digital transmitter/receivers for data communication will permit the measurement of rate of change of azimuth angle and the rate of change of range from ground stations. These stations can be located on a grid referenced basis. This information could be used to calculate aircraft velocities in space in real time with simple computer processes, so providing aircraft track, height and speed.

This navigation system would not only fix the aircraft position, it would be capable of guiding the aircraft along predicted tracks by either air or ground computer. Such a system could also be used for updating aircraft inertial navigation systems and could be considered an inertial navigation reference system.

The data format of the air/ground, ground/air communication link has been designed primarily for aircraft approach guidance purposes. However with the use of suitable sensors and instrumentation in the aircraft and/or on the ground the aircraft transceiver and the ground transponder can be used for significant operational *communication* purposes such as position reporting and airborne target briefing.

The MADGE ground station provides an output containing the identity position range and range rate of any aircraft using the system. It would be a logical extension of the operational capability of the system to interface this data with the *Local Air Defence Control.* Programmed changes of aircraft and ground station address codes could aid positive identification of friendly aircraft and enhance operational security.

MADGE azimuth units together with ground transponders have obvious application to marking dropping zones for *parachute supply.* Flight paths can be defined to permit the use of safe tracks towards and away from Dz. Ground obstructions, high ground and enemy concentrations can be avoided.

All weather operations

The most important operational feature of the MADGE system is that it greatly increases the mobility of air forces irrespective of the nature, location and size of the landing area. MADGE can be deployed in virtually any environment and will permit the movement of aircraft in weather conditions which would otherwise keep them immobile on the ground.

The operational performance of the system can be improved to provide both portable and permanent installations for full automatic landing. This more advanced system is already the subject of advanced research and is expected to be in operational use before the end of the decade.

The MADGE range of systems are all designed to be operationally compatible.

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Further development

The MADGE system concept is considered to provide a facility which probably represents the most significant advance in radio navigation since the Second World War. As described here, the system operates in the 5 GHz band thus its present range of 15–20 nautical miles which is unlikely to be increased much above 30 nautical miles. However MADGE contains all elements which permit the closer integration of the weapon systems of air, land and sea forces thus enhancing the flexibility of response in defence.

The possible future introduction of a portable radio navigation system operating in the 1 GHz band which would make use of the MADGE system concept with range coverage of 150 to 300 nautical miles is foreseen. Such a system is a logical extension of MADGE which would permit integration of even larger defence forces.

The use of a pulse coded modulation system of high integrity provides a fast flexible communication link between the aircraft and the ground for operational control of air, ground and sea weapon systems. It is foreseen that MADGE will lead to the even greater exploitation of such a communication system for the transmission of vital data as a normal operational routine.

Air Defence of the Field Army

By ANDREW BRETT

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Ground defences are one aspect of the total effort to counter enemy air action which embraces attack on hostile air fields, fighter defences and surface-to-air weapons ranging from high altitude SAM to the soldier's small arms.

The accepted British aim for ground-to-air defence, and here I have in mind 1 (British) Corps, is "to prevent the enemy air from interfering with the conduct of ground operations". To some thoughts this may appear to be a narrow and restrictive aim but it is a welcome simplification of the air defender's task where the odds are adverse and his resources are limited. He is therefore not concerned with fighting a counter air battle with the sole aim of destroying hostile aircraft. It is those aircraft attacking or intending to attack the ground forces which he is supporting which are objects of interest; an important consideration in the selection of weapon systems and their employment.

All appreciations of possible future enemy action are speculative to some degree, depending on his strength, intentions and the priority he might give to certain targets. For the purpose of this article we might reasonably assume on the basis of published figures of Soviet air strength that 1 (Br) Corps could expect a minimum of 250 medium and low level sorties in 24 hours. (It should be noted that one "sortie" does not mean one "attack" and one attack does not necessarily mean one successful strike.) This might possibly be increased to more than 1,000 sorties at particular times and places in accordance with the situation. In practical terms, even with the low figure, all of the operational elements of the Corps are likely to be attacked. The highest priority targets within the Corps should expect a number of attacks every 24 hours. With the initiative and the ability to concentrate his forces resting with the enemy the air defender can only hope to use his weapons at their maximum effectiveness.

The threat

For close air support it may be expected that three types of aircraft would figure most prominently in the activities of the Soviet Tactical Air Armies (TAA). Ground attack and reconnaissance would be undertaken by Fitter (Mig 21) and Fishbed (Su 7). Fishbed is the more advanced aircraft and has a secondary role of interceptor. Fitter has a smaller combat radius and is somewhat faster than Fishbed but is a daylight fair-weather machine requiring some two miles of visibility for successful operation. Brewer (Yak 28) would be used extensively for light bombing and reconnaissance. The range of weapons carried by these aircraft are similar to those in general use with Western air forces, gun, cannon, rocket and bomb (including air-to-surface missiles).

The operations of the Tactical Air Army would be confined to the immediate contact zone. Their probable method of attack would be by aircraft in formations of pairs, totalling perhaps some 30 aircraft. Formation leaders navigate and identify the targets. Pairs of aircraft then break off and make individual attacks, coordinated to achieve maximum concentration and so confuse the defences. Spacing between pairs and formations would vary from a few seconds to several minutes. Approach to the target would be at low level, depending on the state of training of the pilots but never more than 300 metres high.

With targets that had already been located the exposure time of the attacking aircraft might be as little as 6–10 seconds, but attacks on targets found in